Florida DOT Specification

SECTION 346
PORTLAND CEMENT CONCRETE

346-1 Description.

Use concrete composed of a mixture of portland cement, aggregate, water, and, where specified, admixtures and pozzolan. Deliver the portland cement concrete to the site of placement in a freshly mixed, unhardened state.

Obtain concrete from an approved concrete production facility meeting the production and Quality Control (QC) of concrete provisions of this Section and Chapter 9.2 of the Materials Manual Concrete Production Facilities Guidelines, which may be viewed at the following URL: http://www11.myflorida.com/specificationsoffice/materialsmanual/section92.pdf. If the concrete production facility's approval is suspended, the Contractor is solely responsible to obtain the services of another approved concrete production facility or await the re-approval of the affected concrete production facility prior to the placement of any further concrete on the project. There will be no changes in the contract time or completion dates. Bear all delay costs and other costs associated with the concrete production facility approval or re-approval.

346-2 Materials.

346-2.1 General: Meet the following requirements:

Coarse Aggregate	Section 901
Fine Aggregate*	Section 902
Portland Cement	Section 921
Water	Section 923
Admixtures	Section 924
Pozzolans and Slag	Section 929

*Use only silica sand except as provided in 902-5.2.3.

Do not use materials containing hard lumps, crusts or frozen matter, or that is contaminated with dissimilar material.

346-2.2 Types of Cement: Unless a specific type of cement is designated elsewhere, use Type I, Type IP, Type IS, Type IP(MS), Type II, or Type III cement in all classes of concrete.

Use only the types of cements designated for each environmental condition in structural concrete. A mix design for a more aggressive environment may be substituted for a lower environmental condition.

TABLE 1			
BRIDGE SUPERSTRUCTURES			
Component	Slightly Aggressive Environment	Moderately Aggressive Environment	Extremely Aggressive Environment
Precast Superstructure and Prestressed Elements	Type I or Type III	Type I or Type III with Fly Ash or Slag, Type II, Type IP, Type IS, or Type IP(MS)	Type II with Fly Ash or Slag
C.I.P. Superstructure Slabs and Barriers	Type I	Type I with Fly Ash or Slag, Type II, Type IP, Type IS, or Type IP(MS)	Type II with Fly Ash or Slag
BRIDGE SUBSTRUCTURE, DRAINAGE STRUCTURES AND OTHER STRUCTURES			
Component	Slightly Aggressive Environment	Moderately Aggressive Environment	Extremely Aggressive Environment
All Structure Components	Type I or Type III	Type I with Fly Ash or Slag, Type II, Type IP, Type IP(MS), or Type IS	Type II with Fly Ash or Slag

346-2.3 Pozzolans and Slag: Use as desired, on an equal weight replacement basis, fly ash, silica fume, metakaolin, other pozzolans, and slag materials as a cement replacement in all classes of concrete, with the following limitations:

(1) Mass Concrete:

a. Fly Ash-ensure that the quantity of cement replaced with fly ash is 18% to 50% by weight.

b. Slag-ensure that the quantity of cement replaced with slag is 50% to 70% by weight. Ensure that slag is 50% to 55% of total cementitious content by weight of total cementitious materials when use in combination with silica fume and/or metakaolin.

(2) Drilled Shaft:

a. Fly Ash-ensure that the quantity of cement replaced with fly ash is 33% to 37% by weight.

b. Slag-ensure that the quantity of cement replaced with slag is 58% to 62% by weight.

(3) For all other concrete uses not covered in (1) and (2) above,

a. Fly Ash-ensure that the quantity of cement replaced with fly ash is 18% to 22% by weight.

b. Slag-ensure that the quantity of cement replaced with slag is 25% to 70% for Slightly and Moderately Aggressive environments, and 50% to 70% by weight when used in Extremely Aggressive environments. Ensure that slag is 50% to 55% of total cementitious content by weight of total cementitious materials when use in combination with silica fume and/or metakaolin.

(4) Type IP (MS): Ensure that the quantity of pozzolan in Type IP (MS) is in the range of 15% to 40% by weight.

(5) Silica Fume and Metakaolin:

a. Cure in accordance with the manufacturer's recommendation and approved by the Engineer.

b. Silica Fume-ensure that the quantity of cement replaced with silica fume is 7% to 9% by weight.

c. Metakaolin-ensure that the quantity of cement replaced with metakaolin is 8% to 12% by weight.

346-2.4 Coarse Aggregate Gradation: Produce all concrete using Size No. 57 or Size No. 67 coarse aggregate. With the Engineer's approval, Size No. 8 or Size No. 89 may be used either alone or

blended with Size No. 57 or Size No. 67. The Engineer will consider requests for approval of other gradations individually. Submit sufficient statistical data to establish production quality and uniformity of the subject aggregates, and establish the quality and uniformity of the resultant concrete. Furnish aggregate gradations sized larger than nominal maximum size of 1.5 inch [37.5 mm] as two components. Ensure the maximum coarse aggregate size does not violate the reinforcement spacing provisions given for reinforced concrete in the AASHTO Standard Specifications for Highway Bridges.

346-2.5 Admixture Requirements: Admixtures will meet the requirements of this subarticle. Chemical admixtures not covered in this subarticle may be approved by the Engineer. Submit statistical evidence supporting successful laboratory and field trial mixes which demonstrate improved concrete quality or handling characteristics.

Do not use admixtures or additives containing calcium chloride (either in the raw materials or introduced during the manufacturing process) in reinforced concrete.

346-2.5.1 Water Reducer/Water Reducer Retardant Admixtures: Use water-reducing admixture, Type A, or water-reducing and retarding admixture, Type D. Use in accordance with the manufacturer's recommended dosage rate.

346-2.5.2 Air Entrainment Admixtures: Use an air entraining admixture in all concrete mixes except counterweight concrete.

346-2.5.3 High Range Water Reducing Admixtures: Use high range water reducing admixtures in concrete mixes incorporating silica fume or metakaolin. Use as desired a High Range Water Reducer (HRWR) admixture, either Type F or Type G, except for concrete used in drilled shafts.

Perform all testing for plastic concrete properties after the HRWR has been added to the concrete mix.

346-2.5.4 Corrosion Inhibitor Admixture: Use only with concrete containing Type II cement, Class F fly ash or slag, and a water reducing retardant admixture, Type D, or High Range Water Reducer admixture, Type G, to normalize the setting time of concrete. Ensure that all admixtures are compatible with the corrosion inhibitor admixture.

346-3 Classification, Strength, Slump and Air Content

346-3.1 General: The separate classifications of concrete covered by this Section are designated as Class I, Class II, Class III, Class IV, Class V and Class VI. Strength, slump, and air content of each class are specified in Table 2:

TABLE 2			
Class of Concrete	Specified Minimum Strength (28-day) (psi) [(MPa)]	Target Slump (inches) [(mm)](c)	Air Content Range (%)
STRUCTURAL CONCRETE			
I (Pavement)	3,000 [21]	2 [50]	1 to 6
I (Special) (a)	3,000 [21]	3 [75] (b)	1 to 6
II (a)	3,400 [23]	3 [75] (b)	1 to 6
II (Bridge Deck)	4,500 [31]	3 [75] (b)	1 to 6
III	5,000 [35]	3 [75] (b)	1 to 6
III (Seal)	3,000 [21]	8 [200]	1 to 6
IV	5,500 [38]	3 [75] (b)	1 to 6
IV (Drilled Shaft)	4,000 [28]	8 [200]	0 to 6
V (Special)	6,000 [41]	3 [75] (b) (d)	1 to 5
V	6,500 [45]	3 [75] (b)	1 to 5
VI	8,500 [59]	3 [75] (b)	1 to 5

(a) For precast drainage products that are manufactured at the precast plant the Contractor is permitted to use concrete meeting the requirements of ASTM C 478 [ASTM C 478M] 4,000 psi [30 MPa] in lieu of Class I or Class II concrete. Apply the chloride content limits specified in 346-4.2 to all box culverts.

(b) The Engineer may allow higher target slump, not to exceed 7 inches [180 mm], when a Type F or Type G admixtures is used.

(c) The Engineer may approve a reduction in the target slump for slip-form operations.

(d) When the use of silica fume or metakaolin is required as a pozzolan in Class V (Special) concrete, ensure that the concrete does not exceed a permeability of 1,000 coulombs at 28-days when tested per AASHTO T 277. Submit 2, 4 x 8 inch [100 x 200 mm] cylindrical test specimens to the Engineer for permeability testing before mix design approval. Submit the test specimens within 7 days prior to the 28-day test. The permeability of the concrete will be taken as the average of two tests, one test per cylinder.

346-3.2 Drilled Shaft Concrete: When drilled shaft concrete is placed in any wet shaft, provide concrete in accordance with the following specified slump loss requirements. When concrete is placed in a dry excavation, do not test for slump loss, except where a temporary removable casing is to be used.

Ensure that drilled shaft concrete has a slump between 7 inches and 9 inches [175 mm and 225 mm] when placed and maintains a slump of 4 inches [100 mm] or more throughout the drilled shaft concrete elapsed time. Ensure that the slump loss is gradual as evidenced by slump loss tests described below. The concrete elapsed time is the sum of the mixing and transit time, the placement time and the time required for removal of any temporary casing that causes or could cause the concrete to flow into the space previously occupied by the temporary casing.

Provide slump loss tests before drilled shaft concrete operations begin, demonstrating that the drilled shaft concrete maintains a slump of at least 4 inches [100 mm] throughout the concrete elapsed time. Inform the Engineer at least 48 hours before performing such tests. Perform slump loss testing of the drilled shaft mix using a laboratory acceptable to the Engineer meeting the requirements of 6-9.

Perform the following procedures for slump loss tests:

(1) Prepare the mix for the slump loss test at a temperature consistent with the highest ambient and concrete temperatures expected during actual concrete placement. Obtain the Engineer's approval of the test temperature.

(2) Ensure that the mix is at least 3 yd^3 [2.3 m^3] and is mixed in a mixer truck.

RESEARCH AND TECHNO-ECONOMIC EVALUATION: USES OF LIMESTONE BYPRODUCTS

FINAL REPORT

Sponsored by the Florida Department of Transportation
State Contract No. BA589
WPI 0510798

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Research was performed at the Department of Geological Sciences, University of Florida. The research program was under the general administration of Mr. Thomas Malerk, State Materials Engineer. The project manager was Mr. John Shoucair, of the State Materials Office, FDOT, Gainesville. The project leader and director was Dr. Guerry H. McClellan.

EXECUTIVE SUMMARY

The stockpiling and disposal of byproduct fines produced by the coarse aggregate industry in Florida is one of the most important problems facing the industry today. Both coarse (minus-3/8" by plus-200 mesh) and fine (minus-200 mesh) fractions of byproduct fines represent highly under-utilized resources suitable to applications in the construction market. This is of particular interest to the Florida Department of Transportation (FDOT), as use of these materials in applications such as engineered backfills, direct addition to concrete mixes as filler (minus-200 mesh), and fine aggregate (minus-3/8" by plus-200 mesh) and agglomeration (minus-200 mesh) for use as a manufactured fine aggregate for flowable fills and concrete offer a means by which the life of a major resource in the state may be extended. Furthermore, use of these materials in high volume, technically and economically feasible applications will lead to both economic and environmental benefits for the coarse aggregate industry through reduced storage and disposal costs, and increased revenues from the sale of fines.

Part I: Evaluation and Characterization of Materials

In order to evaluate the nature of byproduct fines production in the state of Florida, with an emphasis on identifying high volume economic uses for these materials that are attractive to coarse aggregate producers in the state, three goals were identified. The first of these was to estimate the current and future quantity and quality of byproduct resources at selected sites in the state. This was accomplished using a questionnaire and visits to selected producers identified by the Florida Department of Transportation (FDOT) to have significant inventories and/or be future producers of fines and screenings, in order to quantify both the present and future magnitude of the byproduct fines problem. The questionnaire used was modified after one developed by the International Center for Aggregate Research (ICAR) as part of a national study of byproduct fines production.

For the purpose of this report, fines were defined as either coarse (minus-3/8" by plus-200 mesh) or fine (minus-200 mesh), with the fine category representing the greater waste and storage concern as identifying by aggregate producers in the state. Although the quantity of coarse fines produced annually exceeds that of the fine category, producers tend to sell approximately 78 percent of the coarse category as compared to 34 percent of the fine. As a result, producers identified the need for more research and marketing directed at developing products for the minus-200 mesh fines, particularly given that total byproduct fines production is estimated at 300 million tons over the next ten years.

The second goal of the study was to characterize the physical and mineralogical characteristics of these byproduct fines presently stockpiled and sold commercially in both state and national markets. This has been accomplished through an investigation of the particle-size distribution (gradation), moisture content, and mineralogy of byproduct fines collected from coarse aggregate producers identified by the FDOT, representing a variety of limestone and

dolomitic limestone/dolomite lithologies presently exploited by the aggregate industry. Wet sieve analysis of bulk fines, hydrometer test analysis of minus-200 mesh fraction samples, and x-ray diffraction (XRD) of both bulk fines and the acid insoluble fraction (2N HCl) were undertaken in order to satisfy this goal. Evaluation of the resulting compositional and physical data can be used as input in the development of specifications and test procedures used to evaluate and approve fines for the production of manufactured aggregate materials and in other high volume applications. Furthermore, this data should aid in identifying the most appropriate economic use for fines based on spatial constraints associated with lithologic variation.

Part II: Evaluation and Characterization of Products

The third goal of the study was to identify potential economic uses for these fine materials, increase productivity, and extend the life of an important natural resource based on temporal and spatial variations in composition. This has been fulfilled through a review of the literature available on the use of byproduct fines, evaluation of economic data, and testing of processing methods on fines from three sites identified by the FDOT and representing different lithologies. The literature review focused on the published and unpublished literature on agglomeration and/or compaction of fines, as well as relevant computer programs that relate to the production of manufactured aggregate materials. However, other high volume uses which might be of interest to the FDOT (backfill, flowable fill, and direct additives to concrete) were investigated as well.

The four processing methods investigated for the agglomeration of minus-200 (< 75 μm) limestone fines were drum granulation, pan granulation, roll-press flaking, and roll-press briquetting. These processes form the basis for most fine powder agglomeration found in industry today, and are believed to be useful in providing granules for use as aggregate in concrete. All four of the processes have/or are currently being used to produce agglomerated limestone for use as agricultural liming agents.

Based on investment cost data developed for limestone granulation and compaction units (Table 2-1), the cost for a "wet" granulation process (drum granulation and pan granulation) is slightly higher than that for a "dry" compaction unit (roll-press flaking and roll-press briquetting). Most of the cost difference is due to greater costs for instrumentation, piping and ductwork, auxiliary facilities and buildings. The process equipment cost is essentially the same for both units (Tables 2-2 and 2-3) because the cost of the compactor and associated equipment for the compaction plant is about equal to the cost of the granulator and drying system in the granulation plant. Most of the peripheral equipment is about the same for each type of unit.

Tables 2-4 and 2-5 show the calculated conversion costs for both compaction and granulation. This analysis shows that the conversion costs including utilities, labor, maintenance, taxes, insurance, and capital recovery are about 30 % higher for wet granulation than for compaction. Given a yearly production of 78,800 tons, a savings of $488,000 per year would be realized in operating costs with the compaction plant. This would be an ongoing savings in addition to the estimated $296,000 savings in the investment cost for the compaction plant compared to wet granulation.

The key to successfully adapting any one of these processes to produce a granule suitable for aggregate use is through identifying a binder capable of producing a limestone granule with adequate crush strength for use as concrete aggregate. Samples were ultimately granulated using a wet processing method similar to drum granulation, but using a pug mill, as it was determined to be more cost effective, mechanically more simple, and more efficient than any of the other wet or dry processing methods investigated. Sodium silicate, Portland cement, and calcium sulfate hemihydrate ($CaSO_4 \cdot ½H_2O$) were investigated as potential binders.

Final granular aggregate products were evaluated in 2"×2" Portland cement concrete (PCC) test cubes with mixed results. Samples prepared with the sodium silicate binder performed poorly, partially in response to unexpected water solubility of the granules, while the samples prepared with Portland cement as the binder performed much better. Quarry H samples with the Portland cement binder performed almost as well as the Ottawa sand standard, possessing a mean 28-day compressive strength value within 250 psi of the Ottawa sand sample. With the results of the quarry H granules, a reevaluation of the binders used in the granulation process, including binder concentrations, might improve granule strength and PCC test results, providing a valuable, high volume application of granulated byproduct fines as a fine aggregate alternative in PCC or ready mixed flowable fill (RFF).

OBJECTIVES AND SCOPE

The ultimate objective of this research project is to evaluate the nature of byproduct fines production in the state of Florida, with an emphasis on identifying high volume economic uses for these materials which are attractive to coarse aggregate producers in the state. The FDOT is the focus of this project, with the results aimed at enhancing the awareness of FDOT personnel to the geographic distribution, quantities, and properties of coarse aggregate byproducts that may be used as raw material for the production of manufactured aggregates and other secondary applications identified by this study. Phase I of the study is aimed at identifying the volume and characteristics of byproduct fines produced annually in the state of Florida, as well as estimating the quantity and characteristics of byproduct fines already stored at quarries throughout the state. The resulting goals aimed at accomplishing these objectives are:

(1) to estimate the current and future quantity and quality of byproduct resources at selected sites in the state

(2) to characterize the physical and mineralogical characteristics of byproduct fines in Florida presently stockpiled and sold commercially in both state and national markets

The first of these goals was accomplished through the use of a questionnaire (Appendix A) and visits to selected producers identified by the Florida Department of Transportation (FDOT) to have significant inventories and/or be future producers of fines and screenings, in order to quantify both the present and future magnitude of the byproduct fines problem. The questionnaire used in this part of the study was modified after that used by the International Center for Aggregate Research (ICAR) as part of a national study of byproduct fines production.

The second goal was carried out through investigating the particle-size distribution (gradation), moisture content, and mineralogy (including acid insoluble content) of byproduct fines collected from coarse aggregate producers identified by the FDOT as representing a variety of limestone and dolomitic limestone/dolomite lithologies presently mined by the aggregate industry. Wet sieve analysis of bulk fines, hydrometer test analysis of select samples to characterize the particle-size distribution of the minus-200 mesh fraction, and x-ray diffraction (XRD) of both bulk fines and the acid insoluble fraction (2N HCl) have been completed and evaluated in order to satisfy this goal. Collection of compositional and physical data can be used as input in the development of specifications and test procedures which could be used by the FDOT to evaluate and approve fines for the production of manufactured aggregate materials and in other high volume applications. Furthermore, this data should aid in identifying the most appropriate economic use for fines based on spatial constraints associated with lithologic variation.

DATA ANALYSIS

Response to the Information Booklets

At first appearance, the response to the information booklets seems disappointing. Only eleven companies out of about thirty polled responded. However, a closer analysis of the results showed that the mines reported account for about eighty percent of the crushed stone produced annually in Florida. Data on crushed stone production show that Florida produced about 70 million tons in 1996; the annual production at that time from the companies and mines in this study was about 56 million tons. In addition, there is a good geographic distribution of data with reports from all areas except northwest Florida. Four reports are from east and southeast Florida, eight are from southwest Florida, and eight are from south Florida.

Annual Production of Crushed Stone

In 2000, Florida ranked third in the nation in crushed stone production. Between 1971 and 2000, stone production in Florida increased from about 40 million tons per year to about 90 million tons per year (Fig. 1-1). Maximum production was achieved during 2000, when approximately 93 million tons were mined, with a notable production peak during 1988-89 during which about 75 million tons were mined yearly. The overall trend has been a steady increase in production over this three-decade period with rises and falls in production related to general economic conditions. Crushed stone traditionally ranks second, valuewise, to phosphate rock among the mineral commodities mined instate and normally accounts for about 30 percent of Florida's annual mineral value. In 2000, the value of stone mined was valued at $495 million.

The Florida stone industry produces limestone, dolomite, shell, and marl. Limestone accounts for 95 percent or more of the tonnage. Although limestone and dolomite are mined in 22 counties, five counties (Dade, Broward, Hernando, Lee, and Citrus) account for approximately 70% of this production.

Annual Production of Fines

For the purposes of this report, fines are defined in two categories. The coarser class is the minus-3/8" by plus-200 mesh fraction that includes the commercial grade described as "screenings". The second category is the minus-200 mesh fraction. These size fractions may be separated during storage or disposal though some mines discharge mixtures of these sizes in piles and pits. Most fines are created during the crushing and grinding phases of production and seldom exist in substantial quantities in the ore itself. The fine particle sized fractions are removed

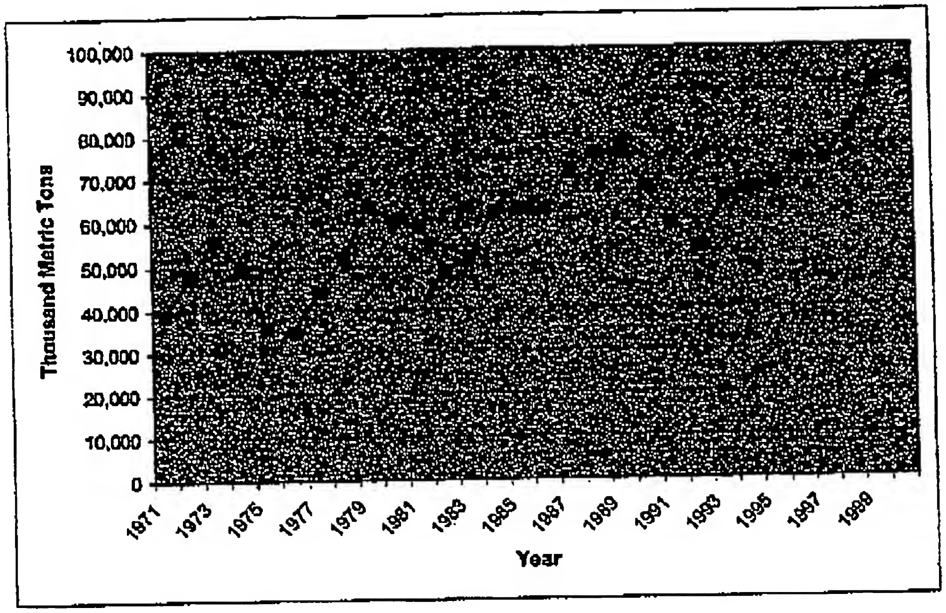

Figure 1-1. Total crushed stone production in Florida (Source: U.S.G.S. Commodity Reports).

from the coarser, more easily saleable products by combinations of washing and screening in one or more steps during processing and sizing.

The minus-3/8" by plus 200-mesh fraction, expressed as a percentage, was obtained for each mine by dividing the minus-3/8" fines produced annually by the total annual production and multiplying by 100. For the data reported, the numerical average production of minus-3/8" is 30 percent of the total annual tonnage (N = 20, Max = 48.3%, Min = 16.7%, Std = 10.6%).

To include the effects of the various annual production rates, a weighted average was calculated as follows:

$$\text{Weighted average} = (AP_m/TP_m)\times(AP_f/TP_f)\times100$$

where,

AP_m = annual individual mine production (i.e., FDOT mine number 99-999)
TP_m = total annual production reported in this survey
AP_f = annual production of fines fraction (either minus-3/8" or minus-200 mesh)
TP_f = total production of individual fine fractions reported in this survey

The weighted average of minus-3/8" material is 14.9 percent, or half the unweighted value. This value is strongly influenced by large producers that have relatively small percentages of their feed reporting to this fraction of fines. The statistics for the weighted average are N = 20,

Max = 7.2%, Min = 0.01, and Std = 2.51%.

The data analysis for the minus-200 mesh fraction shows a numerical average of 13.6 percent where N = 20, Max = 49%, Min = 2.0%, and Std = 14.8%. The numerical average value is rather meaningless with this large standard deviation in the data, but this is an expected result with the great range of values reported for this small data set.

If the data are related to reported annual and total production numbers, the weighted average is 14.2 percent where N = 20, Max = 6.0%, Min = 0.0%, and Std = 2.21%. The weighted average is about the same as the numerical average, but the standard deviation of the data is smaller. This method provides a more meaningful analysis, because the weighting reduces the effect of small producers that generate a significant fraction of minus-200 mesh.

The reporting producers made 21.4 million tons of minus-3/8" fines for the reporting period and sold 16.8 million tons (78 percent). The inventory of this product increased by 4.6 million tons. Respondents reported stockpiles of 75 million tons of minus-3/8" material. During the same period, 8.4 million tons of minus-200 mesh fines were produced, and 2.1 millions tons were sold (34 percent). The inventory of minus-200 mesh fines was increased by 6.3 million tons for the reporting producers. The amount of stockpiled minus-200 mesh material was reported to be 30 million tons. Assuming the factors affecting the respondents are the same for non-reporting crushed stone producers, the statewide total for these inventories can be estimated by increasing these values by twenty-five percent (i.e., 70 Mt produced/56 Mt reported). The resulting inventories would be 94 million tons for the minus-3/8" and 38 million tons for the minus-200 mesh fractions.

These results contain some interesting information. The quantity of minus-3/8" produced per year or in stockpiles is 2.5 times greater than the quantity of minus-200 mesh fines produced. Not surprisingly, a portion of the minus-3/8" material is more readily marketed with nearly eighty percent of current production being sold. Producers report a need for research and marketing assistance in disposing of the minus-200 mesh fines. This may arise from the fact that the minus-200 fraction is accumulating in stockpiles and ponds about fifty percent faster than the minus-3/8" material. The greater moisture contents associated with the very fine fraction materials can result in increased volumes and other problems of storage and handling. In addition, the cost of dewatering fines is under evaluation nationwide by producers who are applying improved mineral processing technologies as the cost effectiveness of these treatments increases.

The data in the information booklets can lead to other interpretations that are important in quantifying the magnitude of the byproduct fines problem in Florida. One of these is based on the history of crushed stone production in Florida. Assuming that the respondents are a representative cross-section of Florida producers and their applied technologies, the weighted averages derived from their input can be applied to the production data for the past 20 years to estimate the quantities of fines that have been produced. In addition, statistical models can be developed to project these numbers into the future. Thus, data analysis methods can be used to estimate the past and future production of fines, allowing a quantitative understanding of the magnitude of this problem.

The U.S. Geological Survey, in cooperation with the Florida Geological Survey, and the former U. S. Bureau of Mines compile statistics on annual crushed stone production for Florida

(see Fig. 1-1). Adding the weighted average for minus-3/8" (14.9 percent) and for the minus-200 mesh (14.2 percent) results in 29.1 percent as the total of byproduct fines produced. The total stone production from 1971-2000 was about 1,900 million tons. Multiplying the cumulative production times the weighted average of byproduct fines shows that the total produced over this period is about 550 million tons (i.e., 19 million tons/year) with nearly equal amounts of minus-3/8" and minus-200 mesh materials. This calculation does not agree with the respondent's data which show more than twice as much minus-3/8" material stockpiled (75 million tons) as minus-200 mesh material (33 million tons). This disparity may result from changes in technology that have reduced the quantity of minus-200 mesh material being produced. The types of stones being mined and milled also may be factors in changing this distribution. The 1997 ICAR study (Hudson et al., 1997) showed that the average production of minus-3/8" material was 22.4 percent of annual production for limestone and dolomite producers. For minus-200 mesh materials from limestone and dolomite producers in the same study, the figure was 3.6 percent. Stockpiles of minus-3/8" and minus-200 mesh fines reported in the ICAR study were 8.18 million and 7.55 million tons, respectively, for limestone and dolomite producers that reported.

In 1971, Florida produced 39 million tons of crushed stone. In 2000, that figure had grown to 93 million tons. Production increased by 54 million tons over a 29-year period (i.e., an average increase of 1.86 million tons/year). Assuming this growth rate will be sustained and using the weighted average production of byproduct fines, future production of fines can be estimated as follows:

$$APF_i = (CP_i + (n \times API)) \times WA$$

where,

APF_i = annual production of fines (in million tons - Mt)
CP_i = year specific annual stone production (in million tons - Mt)
n = number of year in the future
WA = weighted average of byproduct fines production (29.1 percent for this study)
API = annual production increase (1.86 million tons/year for the 29 year period used in this study.

Using this relationship, the annual production of fines for the year 2005 from 2000 data would be:

$$API_{2005} = ((93\text{ Mt}) + (5 \times 1.86)) \times 29.1\% = 29.8\text{ Mt}$$

Similarly, for the year 2010 from 2000 data:

$$API_{2010} = ((93\text{ Mt}) + (10 \times 1.86)) \times 29.1\% = 32.5\text{ Mt}$$

Applying these relationships to project future production shows that annual production will rise from 93 million tons per year in 2000 to about 112 million tons in 2010. The cumulative tonnage of byproduct fines that would be produced during this ten-year period will be

about 300 million tons (154 million tons of minus-3/8" material and 146 million of minus-200 mesh).

Marketing of fines met with variable success depending on the product. For the minus-3/8" material, 16.8 million tons were sold and represented 78 percent of the materials made (in one case 100 percent) and an average of 24 percent of the total stone processed. For the minus-200 mesh fraction, 2.1 million tons were sold representing only 34.4 percent of the product made and 3.2 percent of the stone mined. These figures are quite comparable with the data from the 1997 ICAR study (Hudson et al., 1997) that showed 82.2 percent of minus-3/8" limestone and dolomite and 37.5 percent of the minus-200 mesh were sold by the companies they surveyed. These differences in sales rates impact the proportions of size fractions accumulated in stockpiles where the minus-200 mesh fraction is growing faster than the minus-3/8" material.

CHARACTERISTICS OF FLORIDA BYPRODUCT FINES

In the state of Florida, byproduct fines (both coarse and fine categories) from the coarse aggregate industry are deposited in abandoned quarry pits, collected in stockpiles, and sold as agricultural additives (Aglime) (Figs. 1-2 through 1-5). The byproduct fines vary in age, and as such their condition, often being overgrown by years, if not decades, of vegetation, and represent a major waste storage problem for the Florida aggregate industry. Being that aggregate mining takes place in a variety of locations around the state, which are, in turn, characterized by different geologic formations, often with variations in lithology from location to location (Fig. 1-6), the byproduct fines produced vary, as a result, in their moisture content, particle size characteristics (gradation), and mineralogy. As shown by Stokowski (1993), within source variation of these materials may be just as important as source to source variation, resulting in unique physical, mineralogical, and chemical properties along each point in the coarse aggregate production process. As a result, both source to source and within source variance in material properties are important considerations in the evaluation of potential markets of byproduct fines. Two types of byproduct fines are normally produced during coarse aggregate processing; primary fines and secondary fines. Primary fines (minus-3/8") originate during primary crushing and sizing/washing of aggregate raw materials prior to processing by the commercial products plant (Fig. 1-7). These materials are commonly discarded as waste, while the plus-3/8" material is further crushed and sized/washed to produce commercial coarse aggregate products. Byproduct fines produced during this latter stage of processing are termed secondary fines, and are either discarded as waste, or further processed into fines products (Fig. 1-7). For the purpose of this study, two size fractions of both primary and secondary fines were examined, the coarse fraction (minus-3/8" by plus-200 mesh) including screenings (minus-4 mesh by plus-40 mesh), and the fine fraction (minus-200 mesh). Samples taken for the study are coded in accordance with these size fractions, with identification labels (X-X-X) listing the quarry code (letter A-G), fines type (1 = fine, 2 = coarse, and 3 = screenings), and sample number.

Lithology of Selected Mines

Seven quarries were selected and sampled as part of this investigation to incorporate a variety of lithologies from around the state of Florida (Table 1-1). Lithologies include dolomitic limestone and dolomite from the Suwannee Limestone in Taylor County and the Avon Park Formation in Levy and Citrus counties, as well as limestone from the Suwannee and Ocala limestones in Hernando and Columbia counties and the Tamiami and Ft. Thompson formations in Lee County (Fig. 1-6). As the lithologies studied can be readily separated into dolomitic limestone/dolomite and limestone varieties, these two groups will be examined separately in some detail for both coarse (minus-3/8" by plus-200 mesh) and fine (minus-200 mesh) categories

of fines. Analysis of screenings are included with the coarse category of fines as noted previously.

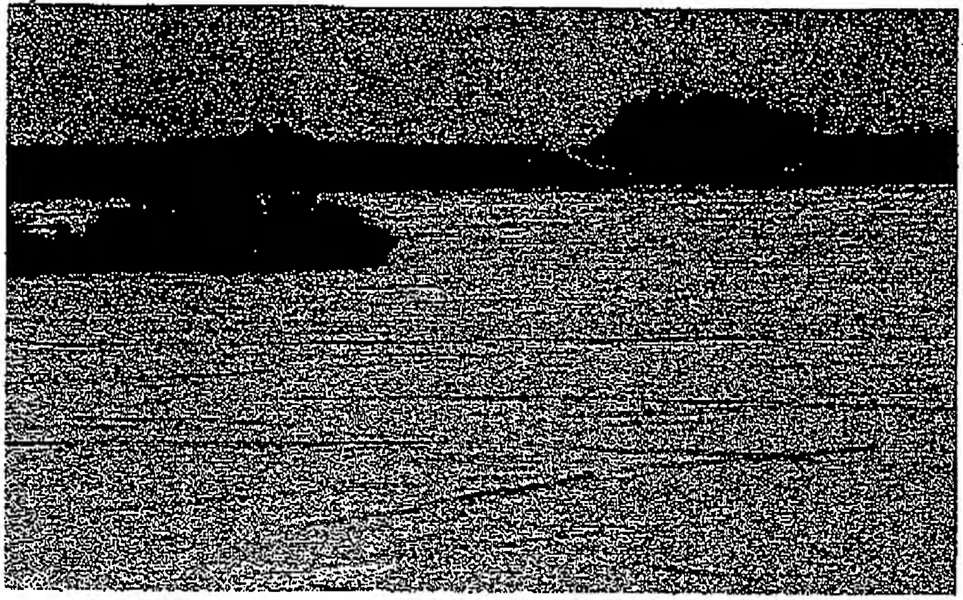

Figure 1-2. Fresh coarse (minus-3/8" by plus-200 mesh) limestone fines collecting in an abandoned mine pit in Hernando County, Florida.